

## OBSERVATION OF ANTIDEUTERON PRODUCTION IN ELECTRON-POSITRON ANNIHILATION AT 10 GeV CENTER OF MASS ENERGY

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The production of antideuterons has been observed in electron-positron annihilations at center-of-mass energies around 10 GeV. Antideuterons have been identified unambiguously by their energy loss in the drift chamber, their time-of-flight and the pattern of their energy deposition in the shower counters of the ARGUS detector. The production rate in the momentum range (0.6–1.8) GeV/c is  $(1.6^{+1.9}_{-0.7}) \times 10^{-5}$  per hadronic event.

*1. Introduction.* The investigation of baryon production in hard interactions has recently become of great experimental [1–5] and theoretical [6–12] interest. A deeper understanding of parton fragmentation is expected to result from these studies since baryons, due to their high mass, reflect more details of the earlier stages of the fragmentation process [13] than the copiously produced mesons. The latter turn out to be dominantly decay products of heavier resonances [14] and therefore reveal only indirect information on parton fragmentation.

Whereas the production of quark–antiquark pairs in electron–positron annihilation is a common feature of all fragmentation models, their descriptions of baryon production differ significantly. Data of higher precision, correlation studies and the investigation of as many baryon channels as possible should allow one to differentiate between the various approaches to parton fragmentation. In this letter we report on the first observation of antideuteron production in electron–positron annihilation, which leads to insight into the production of correlated antibaryon pairs of small relative momentum. A corresponding search for deuteron production in electron–positron annihilation is not possible, since in a significant fraction of beam gas events deuterons are produced. Moreover, the pulse height distribution in the shower counters only allows one to differentiate antideuterons from other hadrons.

The data were collected with the ARGUS detec-

tor at the DORIS II storage ring at DESY. The center-of-mass energies ranged from 9.4 to 10.6 GeV. The detector, its trigger and particle identification capabilities are described in ref. [15]. The event sample used in the analysis corresponds to an integrated luminosity of  $23.6 \text{ pb}^{-1}$  on the  $\Upsilon(1S)$ ,  $38.6 \text{ pb}^{-1}$  on the  $\Upsilon(2S)$ ,  $14.7 \text{ pb}^{-1}$  on the  $\Upsilon(4s)$  and  $7.6 \text{ pb}^{-1}$  in the continuum region.

*2. Selection of antideuterons.* The selection of antideuterons was performed in several steps. As a first step two samples of annihilation events were selected according to the following criteria:

events with  $\geq 3$  charged tracks coming from the vertex  
or

events with  $\geq 3$  charged tracks which are not necessarily produced at the interaction vertex but have an energy of  $\geq 1.7 \text{ GeV}$  detected by the shower counters. 728517 events passed these selection criteria. Next, for each event negative particles with  $|\cos \theta| < 0.7$  originating from the interaction vertex with at least 15 samplings of energy loss in the drift chamber after truncation were selected. In this way an optimal momentum and energy loss determination was secured. In a further selection step the following cuts were applied to select antideuteron candidates:

(i) Truncated energy loss  $dE/dx \geq 4 \text{ keV/cm}$ . This corresponds to more than six standard deviations from the energy loss of high momentum electrons (fig. 1a). Note that the energy loss distribution of particles of given momentum has a gaussian shape as demonstrated by fig. 1b.

(ii) The measured energy loss had to be larger than that expected for a particle of mass  $M = 1.41 \text{ GeV}/c^2$ , unit charge and the momentum measured.

(iii) The standard deviation of the individual energy loss for a track had to be less than 7% of the mean energy loss. This cut rejects tracks which partly overlap with another track or with background hits.

(iv) The track fit probability had to be larger than 1%. This cut removes overlapping and not properly reconstructed tracks. It should be mentioned, however, that the experimental  $\chi^2$  distribution of the track fit deviates considerably from the theoretical one at large values of  $\chi^2$ . The number of tracks rejected by this cut was larger than 1% and varied for different running periods.

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After these selection steps, 16 candidate tracks remained. They were visually scanned. Nine of them turned out to be radiative Bhabha events where the photon converted into an electron-positron pair before entering the drift chamber. The electron track from this pair and the original electron overlapped completely and produced twice the ionization energy loss. This was established by the following observations, valid for all nine events:

(1) The particle with high  $dE/dx$  was accompanied by a positron going in exactly the same direction and by a positron going in the opposite direction. The net charge of the event was thus +1.

(2) The energy deposited in the shower counters coincided within errors, with the center-of-mass energy. The lateral shape of the showers corresponded to the shape of an electromagnetic shower [16].

(3) The missing momentum of the event was within error limits equal to the momentum of the antideuteron candidate.

(4) The time-of-flight information excluded particle velocities  $\beta < 0.8$  while the  $dE/dx$  information required  $\beta < 0.8$ .

A Monte Carlo calculation [17] shows that  $(12 \pm 3)$  events of this type are expected.

One track with high  $dE/dx$  was interpreted as an overlap of two particles in a multihadron event because of the following observations:

(a) The missing  $p_T$  in the event coincided with the  $p_T$  of this track ( $\Delta\phi = 0.04$ ,  $\Delta p_T = 0.24$  GeV/c).

(b) The time-of-flight corresponds to a fast particle ( $\beta = 1 \pm 0.036$ ), while the ionization loss was approximately 2 times that for a relativistic particle. The  $\chi^2$  for the  $\pi^-$ ,  $K^-$ ,  $\bar{p}$  and antideuteron hypothesis was large.

(c) The energy deposited by this track in the shower counters was consistent with that expected from two minimum ionizing particles.

This leaves us with six events containing antideuteron candidate tracks. In these events the setting of the magnetic field, the raw information of all ADC channels, including applied corrections, as well as the time-of-flight and shower counter information were carefully verified.

In fig. 1a the energy loss and the momentum of each antideuteron candidate track are entered. The observed energy loss is in good agreement with that expected for antideuterons.

The antideuteron hypothesis of the six candidates may be checked using the time-of-flight information and the pattern of the energy deposition in the shower counters. The information from the time-of-flight system is compatible with the antideuteron assignment. In three cases the masses are directly measurable ( $m_{\bar{d}} = (1.86 \pm 0.07)$  GeV/c<sup>2</sup>,  $(1.99 \pm 0.13)$  GeV/c<sup>2</sup>,  $(1.86 \pm 0.12)$  GeV/c<sup>2</sup>). For the three other antideuteron candidates, double hits, backscattering due to annihilation of the antideuteron in the shower counters and too high pulse height in the time-of-flight counters respectively prevented the determination of the mass, but the time-of-flight information signalled a slow particle. In each of the six candidate events, the observed energy resulting from the annihilation in the shower counters was compatible with that expected for an antideuteron: the measured energy from the annihilation and the number of neighbouring shower counters set (cluster size) were larger than that observed for all other hadrons, including antiprotons (fig. 2a). Moreover, a pronounced albedo was observed in the drift chamber (fig. 2b), as expected, if the annihilation of a stopped antideuteron takes place in the shower counters.

These three independent methods of identifying the antideuteron are supplemented by the observation that in each of the six events with an antideuteron track at least one proton candidate track was detected. In three of these events at least one unambiguously identified proton track was observed. This may be compared with the measured rate of about 0.2 (anti) protons per hadronic event [1,2] in electron-positron annihilation at  $\sqrt{s} = 10$  GeV.

*3. Results and discussion.* In order to calculate the production cross section from the number of observed antideuterons the acceptance was calculated. It includes the track and the vertex reconstruction efficiency, the antideuteron absorption, the trigger efficiency and the efficiency of the  $dE/dx$  and time-of-flight measurements. The geometrical acceptance was calculated assuming a flat angular distribution. The overall efficiency to detect an antideuteron is 0.55. Using the measured luminosity we arrive at the Lorentz invariant cross section

$$E d^3\sigma/d^3p = (3.1^{+3.0}_{-1.7}) \times 10^{-5} \text{ nb/GeV}^2$$

$$\text{for } 1.97 \text{ GeV} \leq E_{\bar{d}} \leq 2.29 \text{ GeV}$$

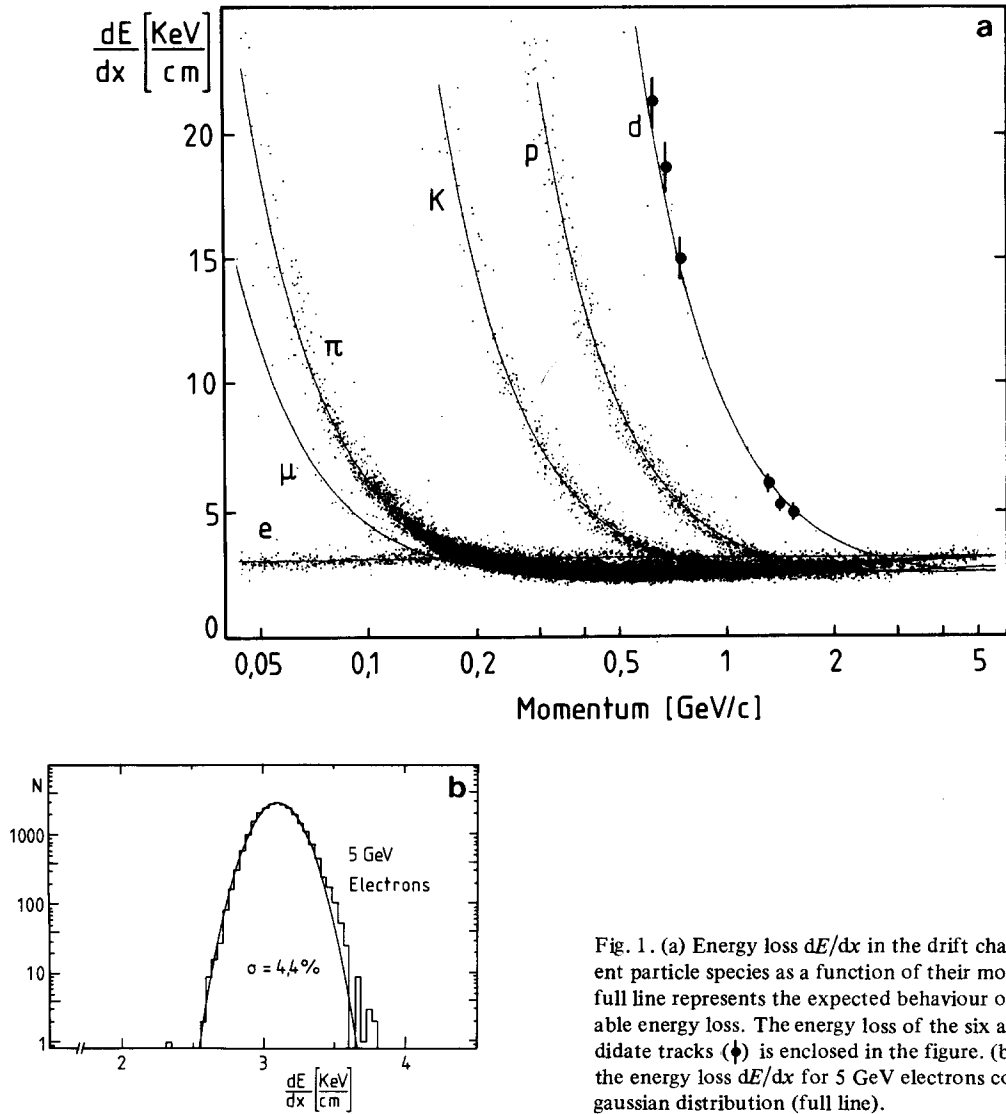


Fig. 1. (a) Energy loss  $dE/dx$  in the drift chamber for different particle species as a function of their momentum. The full line represents the expected behaviour of the most probable energy loss. The energy loss of the six antideuteron candidate tracks ( $\blacklozenge$ ) is enclosed in the figure. (b) Distribution of the energy loss  $dE/dx$  for 5 GeV electrons compared to a gaussian distribution (full line).

and

$$Ed^3\sigma/d^3p = (2.0^{+2.0}_{-1.0}) \times 10^{-5} \text{ nb/GeV}^2$$

$$\text{for } 2.29 \text{ GeV} \leq E_{\bar{d}} \leq 2.6 \text{ GeV}$$

for the production of antideuterons. These cross sections correspond to a production rate in the energy range  $1.97 \text{ GeV} \leq E_{\bar{d}} \leq 2.6 \text{ GeV}$  of  $(1.6^{+1.0}_{-0.7}) \times 10^{-5}$  per hadronic event.

The results are compared in fig. 3 to the produc-

tion cross sections for  $(\pi^+ + \pi^-)$ - and  $(K^+ + K^-)$ -mesons and twice that for antiprotons [1]. Within a factor of 2 the latter cross sections coincide, while the production cross section for antideuterons is suppressed by two orders of magnitude. With the limited statistics of six antideuterons (3 from  $\Upsilon(2S)$ -, 2 from  $\Upsilon(1S)$ - and 1 from  $\Upsilon(4S)$ -energy region), it is not possible to decide whether they come primarily from the three gluon decays or from continuum production.

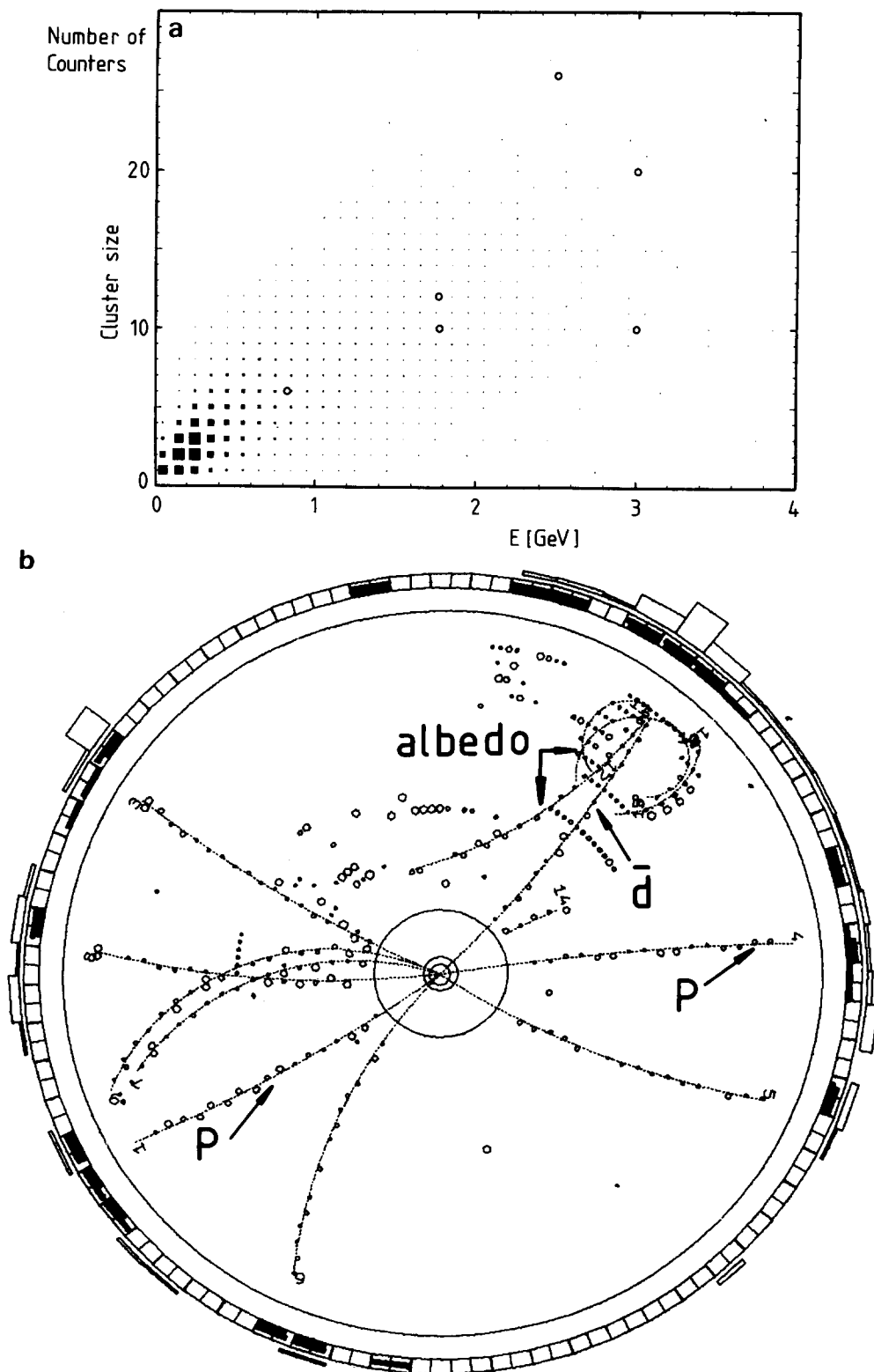


Fig. 2. (a) Energy deposition  $E$  in the shower counters versus cluster size for normal hadronic tracks ( $\bullet$ ) and the six antideuteron candidate tracks ( $\circ$ ). The energy of the backscattered hadrons (not included in  $E$ ) is especially high for those three candidate tracks with the smaller energy deposition  $E$ . The area of the black dots is proportional to the number of entries, the smallest area corresponds to one hadronic track. (b) One event with hits in the drift chamber projected to a plane transverse to the primary beams. The antideuteron track, its albedo and the two proton candidates of the event are labelled.

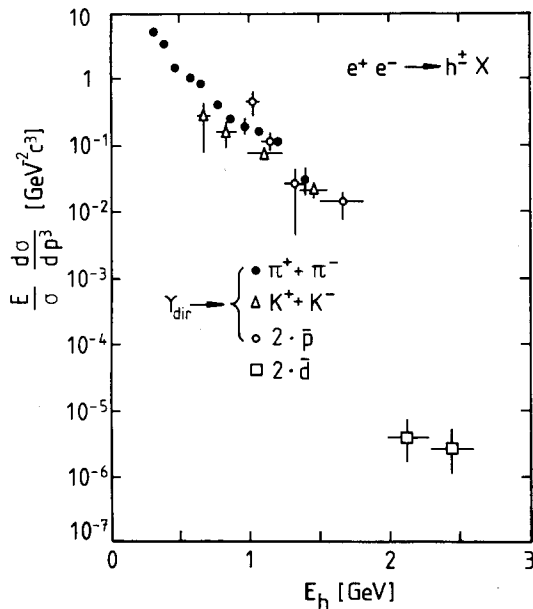


Fig. 3. Measured Lorentz invariant cross section for anti-deuteron production as a function of the particle energy. The results are compared with those for  $\pi^{\pm}$ ,  $K^{\pm}$ - and  $2\bar{p}$  production (DASP II Collaboration [1]).

We have compared the main features of the events containing an antideuteron with those of other hadronic events. Within the large statistical errors no difference in the mean charged multiplicity, the event shape measures or the momentum distribution is observed. The only difference observed is the (expected) increase of proton production in events with an antideuteron track.

In view of the large spatial extension of the antideuteron, its production rate in hard electron-positron annihilations seems to be unexpectedly large. But it is interesting to observe that the rate of antideuteron production

$$r = (N_{\bar{d}}/N_{\pi^-})/(N_{\bar{p}}/N_{\pi^-})^2$$

as measured in this experiment

$$r \approx 2 \times 10^{-3}$$

is of the same order of magnitude as the one observed in proton-nucleon interactions [18] in a broad interval of center-of-mass energies

$$r \approx 5 \times 10^{-3}.$$

The latter observation was interpreted semiquantitatively by a model of Dorfan et al. [19] in which two antinucleons are produced independently in the interaction and form an antideuteron when their wave functions overlap, the antideuteron production rate thus being a measure of antibaryon production at small relative momenta. It is tempting to generalize this model to antideuteron production in electron-positron annihilation.

In summary, we have detected the production of six antideuterons in electron-positron annihilation at  $\sqrt{s} = 10$  GeV. Three independent components of the ARGUS detector have been used to identify the antideuterons. The expected higher proton production rate in events containing an antideuteron, as compared to normal hadronic events, is the only difference observed between these two event samples. The rate  $(N_{\bar{d}}/N_{\pi^-})/(N_{\bar{p}}/N_{\pi^-})^2$  measured in this experiment is of the same order of magnitude as the corresponding rate in soft hadron-hadron interactions.

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